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Introduction

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1.1. Scope of the Assessment

Worldwide concern about possible climate change and acceleration of sea-level rise resulting from increasing concentrations of greenhouse gases has led governments to consider international action to address the issue, particularly through the development of the United Nations Framework Convention on Climate Change (UNFCCC). Because the extent and urgency of action required to mitigate the source of the problem—namely the emission of greenhouse gases by human activities—depends on the level of vulnerability, a key question for the Conference of the Parties (COP) to the Convention, and for policymakers in general, is the degree to which human conditions and the natural environment are vulnerable to the potential effects of climate change. Impact assessments are needed to establish the costs and benefits of climatic change as a guide to what adaptation and mitigation measures might be justified. Without such assessments, we run the risk of making uninformed, unwise, and perhaps unnecessarily costly decisions.

The foundation for policy formulation for the climate change problem is scientific information on greenhouse gas emissions, the climate system and how it may change, and the likely impacts on human activities and the environment. To provide the best available base of scientific information for policymakers and public use, governments have requested that the Intergovernmental Panel on Climate Change (IPCC) periodically assess and summarize the current scientific literature related to climate change. The most recent assessment is the Second Assessment Report (SAR), a comprehensive three-volume report completed in 1995 and published in 1996. This assessment involved extensive inputs from thousands of scientists and was reviewed by governments and leading experts. The SAR takes a global view of the impacts of climate change, organizing chapters by ecosystem type or socioeconomic sector (e.g., forests, grasslands, agriculture, and industry).

In making use of the SAR, the UNFCCC negotiators found a need for more explicit information on how different regions of the world might be affected, to better assess their degrees of vulnerability. Accordingly, the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC requested that the IPCC prepare a report that provided a geographically explicit view of the problem, particularly the vulnerabilities for each region. Initially, a Technical Paper was planned (which, under the IPCC rules of procedure, limited the authors to citing only material included in the SAR), but in September 1996 the IPCC XIIth Plenary at Mexico City decided that a Special Report should be produced. This decision was taken to allow the inclusion and proper review of new material post-dating the SAR—especially new work emerging from several country studies programs, as well as regional studies which were not included in the SAR due to its global scope.

The present report is the result of this process. This report provides assessments of vulnerability of climate change for 10 regions of the globe: Africa, the Arctic and the Antarctic (Polar Regions), Australasia, Europe, Latin America, Middle East and Arid Asia (Arid Western Asia), North America, Small Island States, Temperate Asia, and Tropical Asia. It also includes several annexes that provide information about climate observations, climate projections, vegetation distribution projections, and socioeconomic baseline assumptions used in the report.

1.2. Approach of the Assessment

This report should be read as an assessment of the scientific and technical literature related to the sensitivity, adaptability, and vulnerability of ecosystems and social and economic sectors in the 10 regions—not as a quantitative integrated assessment of impacts. The approach used in preparing the assessment was agreed by the lead authors at a series of scoping meetings held in Washington, DC, in May and September 1996, which set the direction of the assessment when it was being prepared as a technical paper. These meetings were used to review materials from the sectoral assessments of the SAR and organize them into regional analyses, and to identify common issues across the regions and standardize approaches to addressing them. After the paper was reprogrammed as a special report, a series of chapter-specific regional consultations and meetings of lead authors and other experts was held to refine the scope of each regional assessment and to identify studies and methods to use in addition to those used in the SAR. These meetings were held in Toronto, Canada (13–15 January 1997); New Delhi, India (23–25 January 1997); Harare, Zimbabwe (27–29 January 1997); Tarawa, Kiribati (10–13 February 1997); Montevideo, Uruguay (11–13 February 1997); and Amsterdam, The Netherlands (19–21 March 1997).

On the basis of these meetings, the lead authors set about preparing each chapter to provide an assessment of the vulnerability of natural ecosystems, socioeconomic sectors, and human health in the region. The definition of vulnerability used in the SAR was adopted for use by the lead authors in this report: "Vulnerability" is the extent to which climate change may damage or harm a system; it is a function of both the "sensitivity" of a system or structure to climate and the opportunities for "adaptation" to new conditions. Sensitivity is defined as the degree to which a system will respond to a change in climatic conditions (e.g., the extent of change in ecosystem composition, structure, and functioning, including primary productivity, resulting from a given change in temperature or precipitation). The responses may result in either beneficial or harmful effects. Adaptation is defined as adjustments in practices, processes, or structures in response to projected or actual changes in climate. Adjustments can be either spontaneous or planned, reactive or anticipatory. In some cases (e.g., for many ecosystems), options for planned or anticipatory adaptation may not exist. Adaptations can reduce negative impacts or take advantage of new opportunities presented by changing climate conditions. It is in part because of the uncertainties associated with regional projections of climate change (these uncertainties are summarized in Section 1.3.2. and described more fully in Annex B) that this report

takes the approach of assessing vulnerabilities, rather than quantitatively assessing expected impacts of climate change.

This report is based upon evidence found in the published literature, which uses a diverse range of methods and models. This diversity reflects current uncertainties regarding the functioning of complex natural and social systems and how they respond to changes in climate. The assessment did not include the performance of new research or computer model simulations by the authors to estimate impacts under common scenarios of greenhouse gas emissions or climate change. Such work was beyond the scope of the report. Because the available studies have not employed a common set of climate scenarios, and because of uncertainties regarding the sensitivity and adaptability of natural and social systems, the assessment of regional vulnerabilities is necessarily qualitative. Often only very general conclusions can be supported by the currently available evidence. In a number of instances, quantitative estimates of impacts of climate change are cited in the report. Such estimates are strongly dependent upon the specific assumptions made and models used. These estimates should not be interpreted as predictions of the most likely impacts, but rather as illustrations of the potential character and magnitude of impacts that may result from specific scenarios of climate change.

Many impacts studies use model simulations for the equilibrium climatic response to a carbon dioxide (CO_2) doubling, rather than more recent model simulations of climate change resulting from gradually increasing CO_2 concentrations and changing concentrations of aerosols and stratospheric ozone. Thus the level of warming used in many of the impacts studies may not be reached until several decades after 2100, rather than by that date. However, this does not necessarily mean that all impacts will be slowed; for example, the transient simulations exhibit larger land-sea temperature change contrasts, and this would be expected to alter atmospheric circulation and weather patterns in ways not predicted in the equilibrium simulations. Historical observations of the impacts of weather patterns—including droughts, floods, storms, and other extreme weather events—suggest that changes in climate variability could have important impacts on natural and social systems.

Some readers of the special report will be interested only in a particular region, whereas others will be interested in comparing information from different regions. To facilitate such comparison, a common structure, or template, for each regional chapter was developed. The main elements of this chapter template follow:

Executive Summary

Regional Characteristics
- Biogeography (countries, ecosystems, socioeconomic activities covered)
- Trends (key socioeconomic and resource-use information based on data from existing international sources, compiled by the Technical Support Unit in cooperation with World Resources Institute)
- Major climatic zones
- Observed trends for temperature and precipitation (based on IPCC, 1996, WG I, Chapter 3, extended and updated to cover a broader number of contiguous regions)
- Summary of available information on projections of future climate (based on IPCC, 1996, WG I, Chapter 6) and including updated material specific to the region used in regional impact assessments

Sensitivity, Adaptability, and Vulnerability
- Coverage of topics in this section will vary by region, depending on the most important sectors for each region; however, chapters organize the information into the following categories:
  - Ecosystems (including biodiversity)
  - Hydrology/water supply
  - Food and fiber for human consumption (agriculture, forestry, and fisheries)
  - Coastal systems
  - Human settlements and urbanization
  - Human health
  - Other topics particularly relevant to each region (e.g., energy, transport, tourism)

Integrated Assessment of Potential Impacts
- Assessments of illustrative case examples related to ecosystems, water supply/basin management, and socioeconomic activities
- Integrated model results, if available
- Lessons from past fluctuations/variability

This approach is broadly consistent with the seven-step method outlined by the IPCC in its *Technical Guidelines for Assessing Climate Change Impacts and Adaptations* (IPCC, 1994b). These steps are: 1) defining the problem; 2) selecting the method; 3) testing the method/sensitivity; 4) selecting scenarios; 5) assessing biophysical/socioeconomic impacts; 6) assessing autonomous adjustments; and 7) evaluating adaptation strategies.

1.3. Baseline Data and Climate Scenarios

1.3.1. Climate Observations

Current trends in regional variations of temperature and precipitation also are important parts of the baseline against which the potential effects of climate change should be assessed. IPCC (1996, WG I, Chapter 3) provided time series plots and global maps depicting trends for temperature and precipitation. This information was extended and updated by one of the lead authors of the WG I assessment (T. Karl, USA). The information was provided to the regional assessment lead authors and is contained in Annex A of this special report, which describes the data sets used for depicting these trends. Additional information based on regional analyses has been added to several of the regional chapters by the lead authors.

1.3.2. Climate Scenarios

GCM-based scenarios are the most credible and frequently used projections of climate change. Other types of climate projections include synthetic scenarios and analogue scenarios. These approaches and their limitations are described in IPCC (1994b).

In the IPCC's second assessment (1996, WG I, Chapter 6), seven regions were identified for regional analysis of climate simulations. That analysis was based on transient runs with atmosphere-ocean general circulation models (AOGCMs) suitable for construction of regional climate scenarios, using additional regionalization techniques to improve the simulation of regional climate change. The team of lead authors that conducted that analysis, led by F. Giorgi and G. Meehl, prepared information on the simulation of regional climate change with global coupled climate models and regional modeling techniques for use by the regional assessment teams. That information, which is presented in Annex B of this report, is based entirely on the information included in the WG I contribution to the SAR. No new information has been added to the previous analysis.

The wide range of changes in temperature and precipitation indicated at the time of doubled CO_2 concentrations for each region is illustrated in Figures B-1 and B-2, which show large model-to-model differences. Annex B provides the following conclusion regarding the confidence that can be placed in regional climate projections:

> "Analysis of surface air temperature and precipitation results from regional climate change experiments carried out with AOGCMs indicates that the biases in present-day simulations of regional climate change and the inter-model variability in the simulated regional changes are still too large to yield a high level of confidence in simulated change scenarios. The limited number of experiments available with statistical downscaling techniques and nested regional models has shown that complex topographical features, large lake systems, and narrow land masses not resolved at the resolution of current GCMs significantly affect the simulated regional and local change scenarios, both for precipitation and (to a lesser extent) temperature (IPCC, 1996). This adds a further degree of uncertainty in the use of GCM-produced scenarios for impact assessments. In addition, most climate change experiments have not accounted for human-induced landscape changes and only recently has the effect of aerosols been investigated. Both these factors can further affect projections of regional climate change."

The wide range of projected changes in temperature and precipitation suggest that caution is required in treating any impact assessments based on GCM results as firm predictions. This uncertainty is why the term "climate scenarios" has been adopted in most impact assessments. Such scenarios should be regarded as internally consistent patterns of plausible future climates, not as predictions. Decisionmakers need to be aware of the uncertainties associated with climate projections so that they can weigh them in formulation of strategies to cope with the risks of climate change.

The review chapters in this report summarize impact studies based on a range of climate scenarios where they were available. Most studies were based on the older, mixed-layer GCM climate scenarios; results from coupled transient models have only recently become available, and studies using these scenarios are only beginning to be conducted. The older GCM runs estimate stable equilibrium conditions for $1xCO_2$ and $2xCO_2$ climates and generally show more global mean warming than recent transient model runs (see Table 1-1 for a list of equilibrium scenarios used in studies assessed in this special report). In the transient model runs (see Table 1-2 for a listing of transient scenarios cited), in which trace gases increase slowly over a period of years, the full effects of changes in temperature and precipitation lag the effects of changes in atmospheric composition by a number of decades. Thus, in impact studies using transient scenarios (e.g., model studies of potential climate change impacts on vegetation distribution), the positive effects of CO_2 on plant growth and other variables dependent upon plant production precede the full effects of changes in climate.

This complication does not mean that impact assessments based on older equilibrium GCM projections are of no value. Rather, it suggests that their results should be carefully interpreted. Where possible, the actual projected changes in temperature, precipitation, and so forth have been stated in the text, and climate scenarios representing the range of potential changes in temperature and precipitation have been used for regions where a range of scenarios is available. Space limitations prevent the presentation of fine detail, but the original source papers and reports are listed. Unfortunately, even some of the original material does not give as much precise information as might be desired.

At the very least, impact assessments based on older climate scenarios can be used to estimate the sensitivity of the various sectors to climate change. New transient GCMs based on improved coupling to the oceans; better scenarios of greenhouse gas and sulfate aerosol emissions; and better representation of processes of cloud formation, water vapor transport, ice/snow formation, vegetation feedbacks, and ocean circulation will produce quantitatively different results.

1.3.3. Socioeconomic and Resource-Use Baseline Data

The vulnerability of ecosystems and socioeconomic sectors will be affected by their baseline or initial conditions and by the other stresses to which they may be subjected. For this reason, it is important to examine the vulnerability of these systems and sectors in the context of existing and projected developments. To provide a consistent set of socioeconomic and resource-use data, the Technical Support Unit collated data

requested by the authors from, among other sources, *World Resources 1996–97* (WRI/UNEP/UNDP/World Bank, 1996) (see Annex D for a complete list of sources). These data include information on:

- Population and related indicators (1995 population, current population density, projected population density for 2025, and urban and coastal populations)
- Economic indicators [gross domestic product (GDP) per capita; annual growth rate for GDP; and percentage of GDP from agriculture, industry, and services]
- Land cover and use (total land area and amount of land in several categories, including permanent cropland, permanent pasture, forest and woodland, and other land)
- Agricultural activities (amount of irrigated land, size of agricultural labor force, and livestock holdings)
- Water use (water resources per capita and annual water withdrawals for domestic uses, industry, and agriculture)
- Energy use (total commercial energy consumption and consumption of energy sources that are sensitive to changes in climate, including traditional fuels and hydroelectric production)
- Biodiversity (known and endemic mammal, bird, and plant species).

It is important to note that these data are intended simply to provide a consistent set of *assumptions* on important social

Table 1-1: *The global mixed-layer atmosphere-ocean general circulation models (equilibrium 2xCO_2 simulations) used for impact assessment studies in this report.*

Group	Experiment Acronym	Horizontal Resolution (# of waves or lat x long)	Global Surface Air Temperature Change (°C)	Reference(s)
GFDL	A1	R 15	3.2	Wetherald and Manabe, 1988
GFDL	A2	R 15	4.0	Manabe and Wetherald, 1987
GFDL	A3	R 30	4.0	Wetherald and Manabe, 1989
OSU	B1	4°x5°	2.8	Schlesinger and Zhao, 1989
MRI	C1	4°x5°	~4.3	Noda and Tokioka, 1989
NCAR	D1	R 15	4.0	Washington and Meehl, 1984; Meehl and Washington, 1990
NCAR	D2	R 15	4.6	Washington and Meehl, 1993
CSIRO4	E1	R 21	4.0	Gordon *et al.*, 1992; Gordon and Hunt, 1994
CSIRO9	F1	R 21	4.8	Whetton *et al.*, 1993; Watterson *et al.*, 1995
GISS	G1	8°x10°	4.8	Hansen *et al.*, 1984
UKMO	H1	5°x7.5°	5.2	Wilson and Mitchell, 1987
UKMO	H2	5°x7.5°	3.2	Mitchell and Warrilow, 1987
UKMO	H3	2.5°x3.75°	3.5	Mitchell *et al.*, 1989
CCC	J1	T 32	3.5	Boer *et al.*, 1992; McFarlane *et al.*, 1992; Boer, 1993
MPI	K1	T 106[a]	–	Bengtsson *et al.*, 1995, 1996

Note: In general, the findings on impact assessment contained in this report are based on climate change scenarios inferred from the model experiments listed above and cited in IPCC's First Assessment Report (1990) and its supplement (1992).
[a]Time-slice experiments with atmosphere-only ECHAM3 T 106 model.

and economic factors that will influence demands on environmental goods and services (and hence the stresses to which environmental systems may be subjected), as well as the human and financial capacity of societies to adapt to potential climate change. They are not intended to be a definitive source of data on social and economic trends in any particular country. Projections of socioeconomic conditions such as population, incomes, land uses, technological change, economic activity by sector, demands for water and other resources, and other variables are at least as uncertain as regional projections of climate change; as with regional climate information, they should be used as scenarios of future conditions, not treated as predictions.

1.3.4. Development of Integrated Socioeconomic and Climate Change Scenarios

It is important for policymakers to be able to put climate change impacts in the context of other social, economic, and technological conditions, such as:

- Demographic change
- Land-use change
- Land degradation
- Air and water pollution
- Economic and social change, "development" (including technological change), and poverty.

Table 1-2: *A brief description of the global coupled atmosphere-ocean general circulation models (transient simulations) used for impact assessment studies in this report.*

Group	Model Name[a]	Experiment Acronym[b]	Horizontal Resolution (# of waves or lat x long)	GHG Scenario[c]	Global Surface Air Temperature Change at CO_2 Doubling (°C)	Reference(s)
BMRC	–	X1 (a)	R 21	1%/yr	1.35	Colman *et al*., 1995
GFDL	–	X2 (g)	R 15	1%/yr	2.2	Manabe *et al*., 1991, 1992
MRI	–	X3 (p)	4°x5°	1%/yr	1.6	Tokioka *et al*., 1995
NCAR	5° Ocean	X4 (q)	R 15	1%/yr	2.3	Meehl *et al*., 1993
NCAR	1° Ocean	X5 (r)	R 15	1%/yr	3.8	Meehl, 1996 Washington and Meehl, 1996
UKMO	UKTR1	X6 (s)	2.5°x3.75°	1%/yr	1.7	Murphy, 1995; Murphy and Mitchell, 1995; Senior, 1995
UKMO	HADCM2	X7 (z)	2.5°x3.75°	1%/yr + aerosols	~2.5	Mitchell and Johns, 1997
MPI	ECHAM1+LSG	X8 (m)	T 21	1.3%/yr	1.3	Cubasch *et al*., 1992
MPI	ECHAM3+LSG	X9 (y)	T 21	1.3%/yr + aerosols	na	Hasselmann *et al*., 1995
CSIRO	–	X10 (d)	R 21	1%/yr	2.0	Gordon and O'Farrell, 1997
CCC	CGCM1	X11 (b)	T 32	1%/yr	2.6	Boer *et al*., 1997; Flato *et al*., 1997
GISS	–	X12 (k)	4°x5°	1%/yr	1.4	Russell *et al*., 1995

Note: In general, the climate change scenarios described in this document are based on those inferred from the model experiments listed above and reported in the IPCC Second Assessment Report (1996). The future regional projections for combined greenhouse gases (equivalent CO_2) and aerosol forcings (based on experiments X7 and/or X9) also have been discussed for some regions.
na = not available
[a]If different from group name.
[b]Parenthetical refers to experiment listed in Table 6.3 of the SAR Working Group I volume (also see Table B-1 in Annex B).
[c]The GHG scenario refers to the rate of increase of CO_2 used in the model experiments; most experiments use 1%/yr, which gives a doubling of CO_2 after 70 years (IS92a gives a doubling of equivalent CO_2 after 95 years).

Thus, each chapter in this report has a section on "integrated assessment," which attempts to draw together the interactions among sectors, countries, and forces of change. Integrated assessment has been tackled at various levels:

- Integrating the chain of effects from changes in atmospheric composition and climate to changes in biophysical systems to socioeconomic consequences (the "vertical" dimension)
- Including the interactions among systems, sectors, and activities (the "horizontal" dimension)
- Considering climate change in the context of other trends and changes in society (the "time" or "global change" dimension).

Some case study examples have been highlighted in the following chapters, but integrated assessment is in its infancy, and the development of new integrated scenarios of socioeconomic changes, emissions of greenhouse gases, and potential changes in climate was not possible in the time available for preparation of this report. This type of analysis is a priority for the IPCC, however; it currently is the focus of two related activities: a special report on emissions scenarios and a task group on climate scenarios for impact analysis. We expect that the Third Assessment Report (TAR) will be based on such an integrated set of scenarios.

The gaps and deficiencies revealed in this special report suggest some priority areas for further work to help policymakers in their difficult task. These needs include:

- Better baseline data, climate and socioeconomic
- Better scenarios, especially of precipitation, extreme events, sulfate aerosol effects, and regional-scale changes
- Better understanding of the ecological and physiological effects of increasing CO_2 concentrations, taking account of species competition and migrations, soil and nutrients, acclimation, partitioning between crop yields, roots, stems, and leaves
- Dynamic models of climate, biospheric processes, and socioeconomic factors to take account of the developing, time-varying nature of global change
- Impact assessments across a range of scenarios and assumptions to enable the assessment of risk—particularly in regions composed primarily of developing countries, where resources for research and assessment have been inadequate to date
- More and better integrated assessments across sectors, from climate change to economic or other costs, across countries and regions, including adaptations and other socioeconomic changes.

Clearly, impact assessments have not been made across all potentially affected sectors and regions, so many potential costs and benefits remain to be examined and, where possible, quantified. Nevertheless, we believe the present report summarizes a substantial body of work that, if carefully interpreted, may provide useful guidance to policymakers.

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